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Three-dimensional EUV emission and effect of misalignment in laser-droplet interaction

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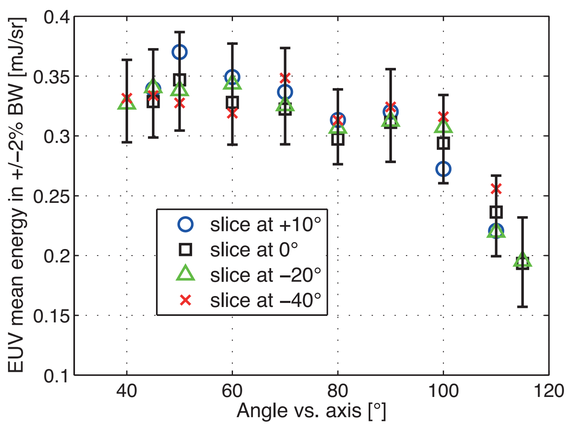
A system has been designed at ETH Zurich, which is capable of generating EUV radiation using droplet targets. It has been shown that the laser-droplet interaction is fully three-dimensional from the EUV emission to the plume expansion. Experiments show the EUV distribution and the effect of the misalignment between the laser spot and the droplet target.

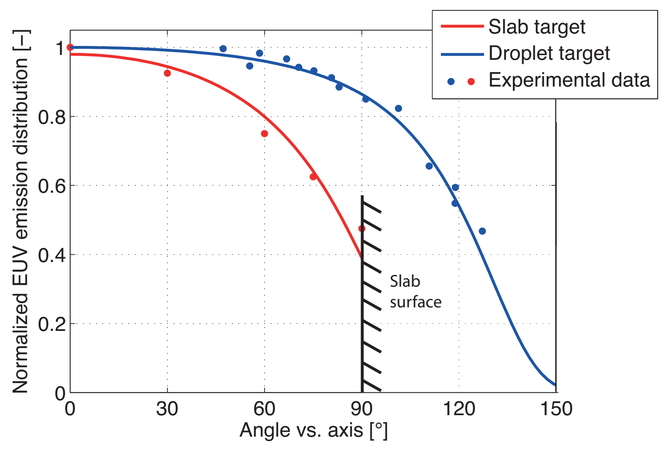
EUV 3D angular distribution

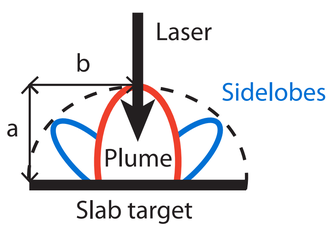
The EUV radiation was measured with an energy monitor, which consists of an aperture, a Mo/Si multilayer mirror of 5° incidence, a Zr filter and an x-ray photodiode.



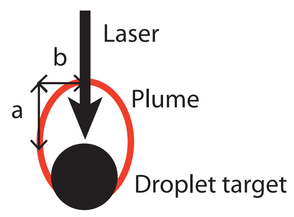
- EUV distribution from the droplet target remains uniform in the hemisphere towards the laser.
- EUV is emitted also behind the droplet target. It was measured up to 120° from the laser axis.
- The EUV emission is extrapolated by the analytical model up to150° from the laser axis.
- The analytical model enables to fit a curve to the measurements, where the free parameter ***b/a*** has a physical meaning: the shape of the ellipsoidal density distribution of the plume.

Difference between slab and droplet target





Model estimation: ***b/a***=1.2



Model estimation: ***b/a***=0.8

The sidelobes production in slab targets is captured by the model through the larger ***b/a*** ratio of 1.2 instead of 0.8 (the ratio between the semi-minor and the semi-major axis of the ellipsoidal iso-density distribution).

Source: A. Z. Giovannini and R. S. Abhari, J. Appl. Phys. 114, 033303 (2013)

Experimental setup

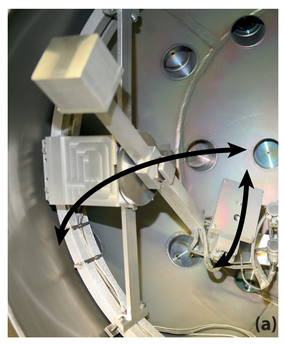
The irradiated targets were tin droplets, with a diameter of 30 µm.

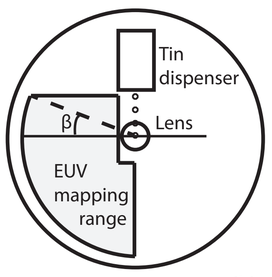
The laser used was a Nd:YAG working at the fundamental wavelength of 1064 nm.

The laser irradiance was 2 x 10^{11} W/cm^2.

The background gas was Argon at a pressure of 0.17 mbar.

The EUV energy monitor was moved by a robotic arm. 88 positions were measured in 1.8 sr in one hemisphere.



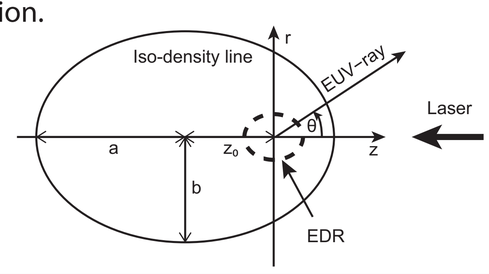


Analytical model

Ellipsoidal density distribution.

EUV absorption is modelled from the density dependent mean opacity.

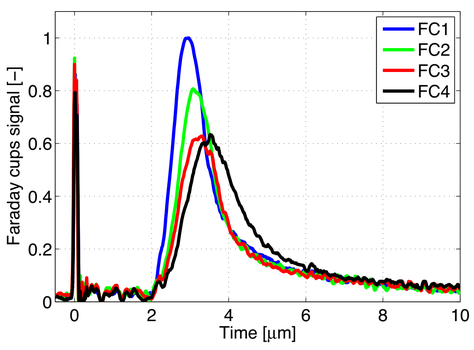
The model relates the plume expansion distribution to the EUV distribution.

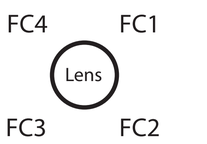


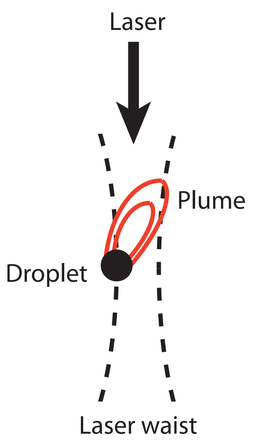
Misalignment effects on EUV radiation and plume expansion

Plume expansion

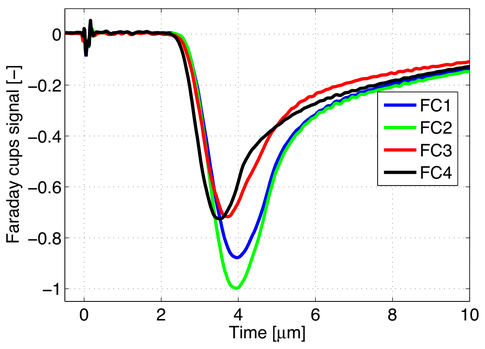
Ions







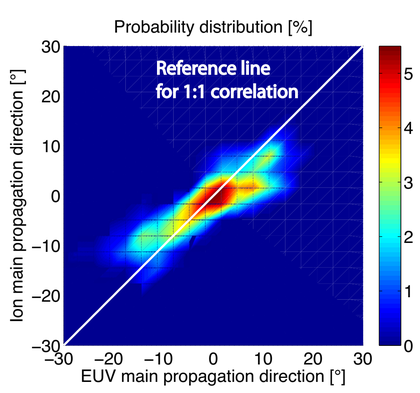
Electrons



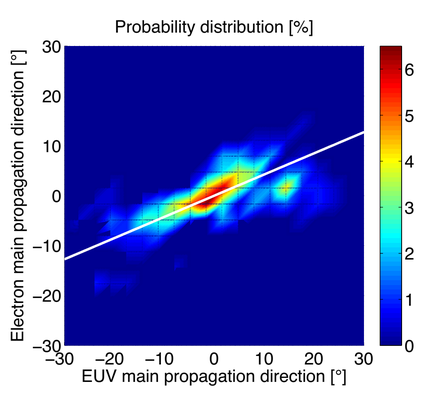
The droplet target has been shifted to the left with respect to the laser axis. The effect on the plume is a rotation of the main propagation direction to the right.

Correlation between plume expansion and EUV emission

Ions

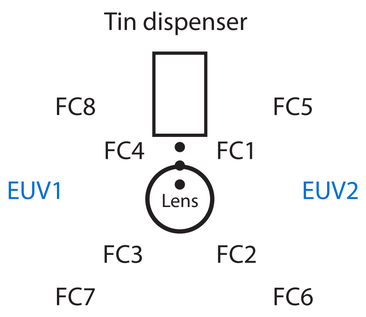


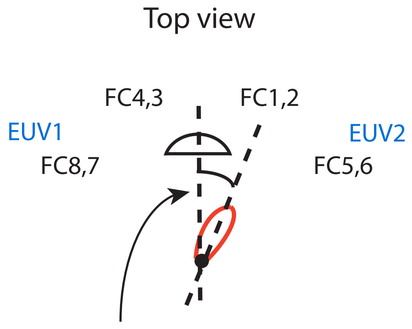
Electrons



- The ion propagation direction for misaligned droplets is coupled to the EUV mean propagation.
- The electrons are less sensitive than ions to misalignment of the droplet.
- It is not possible to place the ML mirrors in a position with maximum EUV emission and no significant ion load.

Experimental setup





Droplets not hit head-on as in normal operation. The misalignment of the droplets with respect to the laser spot is in the order of 10µm.

EUV is measured with 2 Zr coated photodiodes, the detection range is between 6 and 18 nm.
Ions and electrons are measured with Faraday cups (FCs).

All the signals are recorded simultaneously. In this way, every distinct plasma can be studied.

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